(19) Europäisches Patentamt
European Pat nt Office
Office européen des br v ts

(11) EP 0 564 098 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
22.05.1996 Bulletin 1996/21

(51) Int Cl.^{6}: **H01S 3/06**

(21) Application number: **93301641.2**

(22) Date of filing: **04.03.1993**

(54) Variable spectral width multiple pass optical noise source

Optische Mehrfach-Umlauf-Rauschquelle mit variabler spektraler Breite

Source de bruit optique à passes multiples avec largeur variable du domaine spectral

(84) Designated Contracting States:
DE FR GB

(30) Priority: **30.03.1992 US 860636**

(43) Date of publication of application:
06.10.1993 Bulletin 1993/40

(73) Proprietor: **Hewlett-Packard Company**
Palo Alto, California 94304 (US)

(72) Inventors:
- **Baney, Douglas M.**
  Menlo Park, California 94304 (US)
- **Sorin, Wayne V.**
  Mountain View, California 94040 (US)

(74) Representative: **Powell, Stephen David et al**
WILLIAMS, POWELL & ASSOCIATES
34 Tavistock Street
London WC2E 7PB (GB)

(56) References cited:
EP-A- 0 372 907

- **IEEE PHOTONICS TECHNOLOGY LETTERS vol. 2, no. 4, April 1990, NEW YORK US pages 237 - 238 XP000114746 K. IWATSUKI 'Er-doped superfluorescent fiber laser pumped by 1.48 mum laser diode'**
- **OPTICS LETTERS. vol. 15, no. 16, 15 August 1990, NEW YORK US pages 879 - 881 XP000138059 P.F. WYSOCKI ET AL. 'Broad-spectrum, wavelength-swept, erbium-doped fiber laser at 1.55 mum'**
- **ELECTRONICS LETTERS. vol. 28, no. 12, 4 June 1992, STEVENAGE GB pages 1126 - 1128 XP000304631 I.N. DULING III ET AL. 'Single-polarisation fibre amplifier'**

EP 0 564 098 B1

Printed by Jouve, 75001 PARIS (FR)

Description

This invention relates to a system and apparatus for generating an optical noise in a predetermined bandwidth. This optical noise can be used in many applications, such as photodetector calibration and white light spectroscopy. In photodetector calibration the optical noise output, which is relatively flat over a certain bandwidth, is sent to a photodetector. The photodetector's electrical response is then examined on a spectrum analyzer to find distortions which may be caused by the frequency response of the photodetector. In white light spectroscopy, the optical noise output is sent to the material being tested and the absorption spectrum is analyzed.

Prior art optical noise generators include two-pass noise generators which use amplified spontaneous emission (ASE). "High Power Compact 1·48 μm Diode Pumped Broadband Superfluorescent Fibre Source at 1·58 μm"; H. Fevrier, et al.; *Electronic Letters*, Vol. 27, No. 3; Jan. 31, 1991; gives an example of such a noise generator. This article discloses the use of the optical amplifier in a two-pass noise generator as shown in Figure 2. The optical amplifier 10 may consist of a doped amplifying fiber 16 used as the gain medium and a pumping laser 12 which sends optical energy to the doped amplifying fiber via a wavelength division multiplexer (WDM) 14.

Optical noise is spontaneously emitted in the doped amplifying fiber 16 powered by the pumping laser 12. In the system disclosed by Fevrier, optical noise created by spontaneous emission travels through the doped amplifying fiber and is amplified. The amplified optical noise components then go to a mirror 18 which reflects the amplified optical noise components back to the optical amplifier. The optical amplifier amplifies the optical noise components a second time, and then the twice-amplified optical noise components travel to the output.

The pumping frequency of the pumping laser 12 is chosen so that the frequency is absorbed by the doped amplifying fiber 16. The energy from the pumping laser 12 goes through the wavelength division multiplexer 14 to pump the doped amplifying fiber 16 to a higher energy state, so that the doped amplifying fiber 16 will amplify optical signals such as optical noise components coming in through the optical path, and so that the doped amplifying fiber 16 will spontaneously emit light energy.

Looking at Figure 2, the wavelength division multiplexer 14 works by multiplexing the pumping frequency on line B onto line C, so that the doped amplifying fiber 16 can absorb the pumping frequency and amplify the optical signal on the path. Signals going into the wavelength division multiplexer (WDM) 14 from line C will be de-multiplexed into two signals: on line A, the signal which contains the optical noise components not within the pumping frequency; and on line B, the optical signals of the pumping frequency are sent back to the pumping laser.

Other similar prior art systems use a filter at the output of the noise generator so that the optical noise components will be within a desired predetermined bandwidth. Because the filter is placed at the output of the optical path, the optical amplifier amplifies optical noise components that are not within the predetermined bandwidth, during the second amplification of the optical noise components. This unnecessary amplification of optical noise components outside the predetermined bandwidth may cause the optical amplifier to saturate. If the amplifier saturates, the optical noise components within the predetermined bandwidth are not amplified as much as the components would be amplified if the optical amplifier were unsaturated. Additionally, amplifying the optical noise components outside the predetermined bandwidth expends pump power from the pumping laser 12.

It is therefore an object of the present invention to provide a noise source that efficiently uses pump power.

A further object of the invention is to have a noise source that concentrates the available noise power in a narrow optical bandwidth.

EP-A-0372907 discloses in connection with Figure 20 a filtering arrangement for reduction of temperature sensitivity comprising: an amplifying means in an optical path for amplifying optical noise components, said amplifying means including means for producing unpolarized optical noise by spontaneous emission; reflecting means in the optical path for reflecting the optical noise produced by the amplifying means back to the amplifying means for at least one additional amplification; and filter means for filtering out optical noise components outside the predetermined optical bandwidth and for passing optical noise components within the predetermined optical bandwidth, wherein said filter means is located in said optical path so that optical noise components passed by the filter means are amplified by the amplifying means during an additional amplification. This disclosure corresponds generally to the preamble of claims 1 and 7.

According to a first aspect of the present invention there is provided an apparatus for creating optical noise of a predetermined bandwidth comprising:

> amplifying means in an optical path for amplifying optical noise components, the amplifying means including means for producing unpolarized optical noise by spontaneous emission; reflecting means in the optical path for reflecting the optical noise produced by the amplifying means back to the amplifying means for additional amplification; filter means in the optical path for attenuating optical noise components outside the predetermined optical bandwidth; characterised in that the apparatus further comprises:
>
> polarizing means in the optical path for polarizing the optical noise into a component having a first polarization and a component having a second

polarization and for passing optical noise components having the first polarization to an output; and a Faraday rotator in the optical path for rotating the polarization of optical noise components having the second polatization to a third polarization and thereafter for rotating optical noise components having the third polarization back to the first polarization, whereby optical noise components outside the predetermined bandwidth are attenuated on successive passes and optical noise components within the predetermined bandwidth are amplified on successive passes and passed to the output upon rotation to the first polarization.

According to a second aspect of the present invention there is provided a method of creating optical noise of a predetermined bandwidth, the method comprising the steps of:

(a) generating optical noise by spontaneous emission;
(b) directing the optical noise along an optical path that passes through an amplifier a plurality of times;
(c) filtering the optical noise as it propagates along the optical path to attenuate optical components outside the predetermined bandwidth; characterised in that the method comprises the further steps of:
(d) polarizing the optical noise as it propagates along the optical path into a component having a first polarization and a component having a second polarization;
(e) rotating the polarization of the optical noise on successive passes through the amplifier such that after a plurality of passes through the amplifier the polarization of any component not having the first polarization has been rotated to the first polarization; and
(f) passing any optical noise component that has the first polarization to an output.

An advantage of the present invention is the placement of a filter so that the optical amplifier as a noise source does not amplify optical noise components outside the bandwidth of interest during at least one amplification. This placement of the filter may prevent the optical amplifier from becoming saturated by noise outside the filter bandwidth.

The above and other features and aspects of the present invention will become more apparent upon reading the following detailed description in conjunction with the accompanying drawings, in which:

Figure 1 is a schematic view of an optical noise. source apparatus not in accordance with but useful for understanding the present invention;
Figure 2 is a schematic view of the prior art optical amplifier including a pumping laser, a wavelength division multiplexer, and a doped amplifying fiber;
Figure 3 shows the four-pass noise source of the present invention;
Figure 4 shows a schematic view of an alternate four-pass noise source design of the present invention; and
Figure 5 is a schematic view of a four-pass noise source of the present invention where the paths of the optical noise components are shown below.

Figure 1 is a schematic view of a two-pass noise source not in accordance with but useful for understanding the present invention. An optical amplifier 2 such as the prior art optical amplifier shown in Figure 2 is placed in the optical path. The components of the optical amplifier in the preferred embodiment include the pumping laser, WDM and doped amplifying fiber as described in the discussion of Figure 3 below.

It is to be understood that other types of optical amplifiers could be used to create and amplify optical noise. For example, a co-propagating optical amplifier could be used. The optical amplifier shown in Figure 2 is called a counter-propagating optical amplifier since the pumping signal from the pumping laser travels to the amplifying fiber in the opposite direction from the optical noise as it leaves the noise generator. A copropagating optical amplifier would have the WDM and pumping laser located to the left of the doped amplifying fiber so that the pumping signal travels in the same direction as the optical noise as the optical noise leaves the noise generator.

The mirror 6 is used to reflect the optical noise back to the amplifier and can alternatively be replaced by a Sagnac loop, which is a 3dB coupler connected to a loop of fiber. In general, any means that causes the optical noise components to travel back to the amplifying means may be used as a reflective means and is within the scope of the invention. A filter 4 is also placed in the optical path. One embodiment uses a transmissive tunable filter which is tunable between 1515-1560 nm with a 1nm to 5nm bandwidth. The noise source with a tunable filter may operate as a tunable non-coherent optical source.

In the two-pass noise source of Figure 1, unpolarized optical noise is created by spontaneous emission in the optical amplifier 2. More specifically, the spontaneous emission occurs in the doped amplifying fiber 16 of the prior art optical amplifier shown in Figure 2. The unpolarized optical noise can either go towards the mirror 6 or towards the output 8. If the unpolarized optical noise goes towards the mirror 6, the optical noise is amplified in the optical amplifier a first time, and is filtered in the filter 4. The filter 4 filters the once-amplified optical noise components to within the predetermined bandwidth, and passes these filtered components to the mirror 6. The mirror 6 reflects the amplified optical noise components back through the filter towards the optical amplifier 2. Next, the amplified optical noise compo-

nents are amplified a second time in the optical amplifier 2, and then sent to the output 8.

Since the optical noise components are filtered in the filter 4 before going into the optical amplifier 2 for an additional amplification, the optical amplifier 2 does not amplify for a second time the optical noise components that are not within the predetermined optical bandwidth.

At the output, these filtered twice-amplified optical noise components dominate over the once-amplified optical noise components created by spontaneous emission that go directly towards the output 8.

Figure 3 shows a schematic view of a four-pass noise source of the present invention. This apparatus includes an optical amplifier 20 comprised of a doped amplifying fiber 22, such as Erbium doped fiber, a WDM 24 and a pumping laser 25. The pumping laser 25 can be a multimode or a single wavelength laser. In one embodiment of the present invention, the pumping laser 25 is a commercially available laser diode with a wavelength of 980 nm or 1480 nm. The wavelength division multiplexer (WDM) 24 used in the preferred embodiment is commercially available from Gould Electronics of Glen Burnie, Maryland and such WDM's are often used in telecommunications applications. The preferred embodiment of the invention uses Erbium doped fiber as the amplifying fiber 22. Other doped amplifying fibers such as Praseodymium fiber, Neodymium fiber, Promethium fiber, and Ytterbium fiber can also be used.

Two lenses 26 and 28 are shown that collimate the optical components as they leave the optical fiber 27 out of the ends 46 and 44.

Also shown is a reflective filter 32. This reflective filter 32 acts as both the reflecting means to reflect the optical noise components back toward the amplifier, and a filtering means to filter out the optical noise components not within the predetermined optical bandwidth and pass optical noise components within the predetermined optical bandwidth. The optical noise components that are within the predetermined optical bandwidth are passed back towards the optical amplifier 20, and the optical noise components not within the predetermined bandwidth are no longer present in the optical path.

The optical path also includes a Faraday rotator 30. The Faraday rotator 30 rotates the polarization of the optical noise components that go through it. A Faraday rotator in the preferred embodiment rotates the polarization of the optical noise components by 45° for each pass. In the preferred embodiment, the Faraday rotator 30 consists of a piece of Faraday-active material of the dimensions 2mm x 2mm x 300μm (not shown) placed in a one-half inch cavity within a permanent magnet. This Faraday-active material may be a piece of (HoTbBi)IG from Mitsubishi Gas Chemical Company Inc. of Tokyo, Japan, but other types of Faraday- active material may be used.

A reflective filter 34 and a polarizing beam-splitter 36 form a polarizing means. The polarizing beamsplitter 36 of the preferred invention is commercially available from the Melles Griot company of Los Angeles, California and consists of a glass cube 20mm x 20mm x 20mm made of two triangular sections connected together. The polarizing beamsplitter 36 splits the unpolarized optical noise components sent from the optical amplifier 20 into two different orthogonal polarizations. For example, in one embodiment TE polarized optical noise components are sent to the output 40, and TM polarized optical noise components pass through the polarizing beamsplitter 36 to the reflective filter 34. The optical noise components that are within the predetermined optical noise bandwidth are passed back from the reflective filter 34 through the polarizing beamsplitter 36 to the amplifier 20.

The preferred embodiment of the four-pass optical noise source includes a delay line 42. The two ends 44 and 46 of the optical fiber 27 that contains the optical amplifier and the delay line 42, would ideally cause no reflections of the optical components that leave ends 44 and 46. In a real apparatus, however, some of the optical noise components that exit the optical fiber 27 are reflected back. This reflection may cause ripples in the output signal.

The delay line 42 is made up of a single mode fiber and in the preferred embodiment is 500m long. The delay line 42 can be used if there are ripples in the output signal coming from the output 40 of the noise source to the device 49 that uses the output signal. If the device 49 that uses the four-pass optical noise source has a detection bandwidth $\Delta\nu_{det}$ that is much greater than $1/\tau$, where τ is the length of the delay line 42, the ripples in the output can be averaged out. This is because the frequency of the ripples in the output signal is less than the minimal resolvable frequency of the device 49 that uses the output signal.

The action of the optical noise components in the four-pass optical noise source can be better explained using the schematic diagram of Figure 5. Figure 5 shows a four-pass noise source similar to that in Figure 3. However, Figure 5 uses a transmissive filter 80 located between the lens 82 and the polarizing beamsplitter 84. This transmissive filter 80 does not allow any optical noise components outside the predetermined optical bandwidth to pass from the amplifier to the polarizing beamsplitter 82. Placing the filter at this position has the benefit of filtering the optical noise components right before the signal is sent to the output. The transmissive filter 80 placed in this position will also filter the optical noise components before the optical noise components' third and fourth amplification.

The steps that the optical components take in the four-pass optical noise generator are shown in the arrows and letters at the bottom of Figure 5.

In step A, an unpolarized optical noise is spontaneously emitted in the doped amplifying fiber 90 of the optical amplifier, which consists of the doped amplifying fiber 90, the wavelength division multiplexer or WDM 92, and the pumping laser 94. The spontaneously emitted

optical noise leaving the doped amplifying fiber is unpolarized. This spontaneously emitted unpolarized optical noise can either go towards the Faraday rotator 96 and mirror 98 or go towards the polarizing beamsplitter 84.

If the unpolarized optical noise goes towards the Faraday rotator 96 and mirror 98, then in step B the optical noise components are amplified a first time, sent out the optical fiber to the lens 86, passed through the Faraday rotator 96 and rotated 45°. Since the optical noise components are unpolarized, the 45° optical rotation leaves once-amplified optical noise components unpolarized.

In step C, the unpolarized once-amplified optical noise components reflect off the mirror 98 back towards the amplifier. The once-amplified optical noise components, which are unpolarized, pass through the Faraday rotator and are rotated another 45°, but remain unpolarized, and go through the lens 86 back to the optical fiber, and to the doped amplifying fiber 90.

In step D, the optical noise components are amplified a second time to create twice-amplified optical noise components which are unpolarized. These components then pass through the wavelength division multiplexer 92 and most of the unpolarized twice-amplified noise components, including all of the twice-amplified optical noise components that are within the predetermined bandwidth, pass through the WDM 92 out of the optical fiber through the lens 82. This occurs because the WDM passes the relevant optical noise components through to the lens 82 and sends an optical bandwidth including the pumping frequency to the pumping laser. The optical bandwidth that is sent by the WDM 92 to the pumping laser 94 is not part of the predetermined optical bandwidth of the four-pass noise source.

In step E, the twice-amplified unpolarized optical noise components are filtered in the transmissive filter 80 so that only the optical noise components within the predetermined optical bandwidth pass through to the polarizing beamsplitter 84. The polarizing beamsplitter 84 polarizes the twice-amplified unpolarized optical noise components. The twice-amplified optical noise components of a first polarization leave the polarizing beamsplitter 84 out to the output 102 as shown in step F'. The twice-amplified optical noise components of a second polarization pass through the polarizing beamsplitter 84 to the mirror 100 in step F. In the preferred embodiment, the second polarization is orthogonal to the first polarization.

In step G, the twice-amplified optical noise components of the second polarization rebound back towards the amplifier.

In step H, these components are filtered again in filter 80, pass through the lens 82 back into the optical fiber, and pass through the wavelength division multiplexer 92 to the doped amplifying fiber 90. The WDM 92 multiplexes the components with the pumping frequency of the pumping laser 94. The pumping frequency is then absorbed by the doped amplifying fiber 90.

In step I, the signal is amplified a third time to create thrice-amplified optical noise components of the second polarization. These components leave the optical fiber through the lens 86 to the Faraday rotator 96.

In step J, the signal is rotated 45° in the Faraday rotator 96 from the second polarization to a third polarization to create thrice-amplified optical noise components of the third polarization. These components are sent to the mirror 98. In step K, the components are reflected back through the Faraday rotator 96, which rotates the thrice-amplified optical noise signal components by 45° from the third polarization to the first polarization, and then sends the components back through the lens 86 to the optical fiber.

In step L, the noise is amplified in the doped amplifying fiber 90, to create four-times-amplified optical noise components of the first polarization. This noise then goes through the wavelength division multiplexer 92 and passes out through the lens 82.

In step M, the components are filtered for a last time in the transmission filter 80. The four-times-amplified optical noise components of the first polarization pass through the polarizing beamsplitter 84 to the output 102.

The four-times-amplified optical noise components dominate over the other components such as the twice-amplified optical components which are output in step F'. Additionally, the optical noise components that go towards the mirror 100 in step A instead of towards the mirror 98 as shown in step B would be at most thrice-amplified. These components are only thrice amplified because these components go through the doped amplifying fiber 90, are polarized, reflect off the mirror 100, come through the fiber again to be amplified a second time, are rotated in the Faraday rotator 96 twice, amplified the third time, and then sent to the output 102 through the polarizing beamsplitter 84.

If no filtering was used, the power at the output port would be approximately (neglecting optical coupling loss):

$$P_{out} \approx n_{sp} G^4 h\nu \Delta\nu$$

where G is the single-pass optical gain typically around 25dB, n_{sp} is a term proportional to the level of inversion in the doped amplifying fiber, h is Planck's constant, ν is the center frequency, and Δν is the optical bandwidth.

If filtering is used, then Δν stands for the bandwidth of the filter. The use of the filter will prevent noise from outside the optical bandwidth from saturating the amplifier and therefore the gain within the bandwidth of the filter is increased. A 1nm bandwidth is sufficient to test the frequency response of high speed photodiodes. With a 1nm bandwidth filter it is estimated that the noise power will be of the order of 10mW/1nm.

The use of four-pass gain results in efficient use of the pump power because the optical noise components have four times the possibility to delete the upper energy state, thus causing increased pump absorption. Addi-

tionally, since the pump absorption is enhanced, shorter doped amplifying fiber lengths can be used, which reduces the cost of the doped amplifying fiber.

Figure 4 is a schematic diagram of an alternate embodiment of a four-pass noise source. This alternate embodiment is most useful if the optical fiber does not display a birefringence effect. Figure 4 shows the amplifier 50 which can be constructed out of the components shown in Figure 2; a pumping laser 12, WDM 14 and doped amplifying fiber 16. An unpolarized optical signal is created by spontaneous emission in the amplifier 50. This signal moves to the mirror 52, which reflects it back to the amplifier 50 to create twice-amplified optical noise components which are unpolarized. These components are sent to the Faraday rotator 54, which then rotates the polarization of the signal. Since the signal is unpolarized, however, the components remain unpolarized after leaving the Faraday rotator 54. The components then go to the filter 56 which filters out the optical noise components that are outside of the predetermined optical bandwidth. The twice-amplified optical noise components which have been filtered are then sent to the polarizing beamsplitter 58, where the twice-amplified optical noise components are split into two different polarizations. The twice-amplified optical noise components of the first polarization are sent to the output 62. The twice-polarized optical noise components of the second polarization are sent to the mirror 60, which then reflects the component back through the polarizing beamsplitter to the filter 56 and to the Faraday rotator 54. The Faraday rotator rotates the polarization of this signal to create twice-amplified optical noise components of the third polarization.

In the preferred embodiment, a 45° rotation of the components' polarization is created in the Faraday rotator. The twice-amplified optical noise components of the third polarization are then amplified in the amplifier 50 to create thrice-amplified optical noise components of the third polarization. These components then go to the mirror 52, which reflects them back towards the amplifier 50. In the amplifier 50, thrice-amplified optical noise components of the third polarization are amplified to create four-times-amplified optical noise components of the third polarization. These components go through the Faraday rotator 54, which rotates them from the third polarization to the first polarization to create four-times-amplified optical noise components of the first polarization. The optical signal is filtered again to remove the optical noise components outside the predetermined optical bandwidth, and then sent to the polarizing beamsplitter 58, which then sends the four-times-amplified optical noise components of the first polarization to output 62. The filtered four-times-amplified optical noise components of the first polarization dominate the output.

If there is a birefringence effect in the optical fiber, then it is preferred to place the Faraday rotator next to the mirror or reflective filter. Looking at Figure 5, the Faraday rotator 96 in the preferred implementation is placed next to the mirror 98. When a 45° Faraday rotator is placed next to the reflecting means, the Faraday rotator compensates for birefringence changes induced on optical signals in the optical fiber 27 shown in Figure 3. Because of this compensation, an optical component that enters the optical fiber during step H will be orthogonally polarized to the optical component exiting the optical fiber during step L despite any birefringence effect in the optical fiber.

If the Faraday rotator was placed as in Figure 4 on the other side of the amplifier 50 and optical fiber (not shown), then the birefringence effect in the optical fiber, especially the birefringence effect due to any delay line, would affect the polarization of the components sent to the polarizing beamsplitter 58.

The change in the polarization of the optical components due to the birefringence effect or the $\delta\Theta$ error in the Faraday rotator away from 45° needs to be small or lasing will occur in the apparatus.

Various details of the implementation and method are merely illustrative of the invention. It will be understood that various changes in such details may be within the scope of the invention, which is to be limited only by the appended claims.

Claims

1. An apparatus for creating optical noise of a predetermined optical bandwidth comprising:

amplifying means (20,50,93) in an optical path for amplifying optical noise components, the amplifying means (20,50,93) including means for producing unpolarized optical noise by spontaneous emission;
reflecting means (32,34; 52,60; 98,100) in the optical path on both sides of said amplifying means for reflecting the optical noise produced by the amplifying means (20,50,93) back to the amplifying means (20,50,93) for additional amplification;
filter means (32,34; 56;80) in the optical path for attenuating optical noise components outside the predetermined optical bandwidth;
characterised in that the apparatus further comprises:
polarizing means (36,58,84) in the optical path for polarizing the optical noise into a component having a first polarization and a component having a second polarization and for passing optical noise components having the first polarization to an output (40,62,102); and
a Faraday rotator (30,54,96) in the optical path for rotating the polarization of optical noise components having the second polarization to a third polarization and thereafter for rotating optical noise components having the third

polarization back to the first polarization, whereby optical noise components outside the predetermined bandwidth are attenuated on successive passes and optical noise components within the predetermined bandwidth are amplified on successive passes and passed to the output upon rotation to the first polarization.

2. The apparatus of claim 1, wherein the filter means (80) comprises a transmissive filter.

3. The apparatus of claim 1, wherein the reflecting means (32) and the filter means (32) are comprised in a reflective filter.

4. The apparatus of any preceding claim, wherein the polarizing means (36,58,84) comprises a polarizing beamsplitter.

5. The apparatus of any preceding claim, wherein the amplifying means (20,50,93) comprises a pumping laser (25,94), a wavelength division multiplexer (24,92) and a doped amplifying fibre (22,90).

6. The apparatus of any preceding claim, further comprising a delay line (42) in the optical path.

7. A method of creating optical noise of a predetermined bandwidth, the method comprising the steps of:

(a) generating optical noise by spontaneous emission;
(b) directing the optical noise along an optical path that passes through an amplifier (20,50,93) a plurality of times;
(c) filtering (32,34; 56;80) the optical noise as it propagates along the optical path to attenuate optical components outside the predetermined bandwidth; characterised in that the method comprises the further steps of:
(d) polarizing (36,58,84) the optical noise as it propagates along the optical path into a component having a first polarization and a component having a second polarization;
(e) rotating (30,54,96) the polarization of the optical noise on successive passes through the amplifier such that after a plurality of passes through the amplifier the polarization of any component not having the first polarization has been rotated to the first polarization; and
(f) passing any optical noise component that has the first polarization to an output (40,62,102).

8. The method of claim 7, wherein the optical path extends from a first port of the amplifier (20) through a Faraday rotator (30) to a reflective filter (32) and thence back through the Faraday rotator to the amplifier, and from a second port of the amplifier (20) through a polarizer (36) to another reflective filter (34) and thence back to the amplifier.

9. The method of claim 7, wherein the optical path extends from a first port of the amplifier (93) through a Faraday rotator (96) to a reflector (98) and thence back through the Faraday rotator to the amplifier, and from a second port of the amplifier (93) through a polarizer (84) to another reflector (100) and thence back to the amplifier, and through a filter (80).

10. The method of claim 7 wherein the optical path extends from a first port of the amplifier (50) to a reflector (52) and thence back to the amplifier, and from a second port of the amplifier (50) through a Faraday rotator (54) and a polarizer (58) to another reflector (60) and thence back to the amplifier, and through a filter (56).

Patentansprüche

1. Eine Vorrichtung zum Erzeugen eines optischen Rauschens einer vorbestimmten optischen Bandbreite mit folgenden Merkmalen:

einer Verstärkungseinrichtung (20, 50, 93) in einem optischen Weg zum Verstärken optischer Rauschkomponenten, wobei die Verstärkungseinrichtung (20, 50, 93) eine Einrichtung zum Erzeugen eines unpolarisierten optischen Rauschens durch eine Spontanemission aufweist;

einer Reflexionseinrichtung (32, 34; 52, 60; 98, 100) in dem optischen Weg auf beiden Seiten der Verstärkungseinrichtung, um das optische Rauschen, das durch die Verstärkungseinrichtung (20, 50, 93) erzeugt wird, für eine zusätzliche Verstärkung zu der Verstärkungseinrichtung (20, 50, 93) zurückzureflektieren;

einer Filtereinrichtung (32, 34; 56; 80) in dem optischen Weg zum Dämpfen optischer Rauschkomponenten außerhalb der vorbestimmten optischen Bandbreite; dadurch gekennzeichnet, daß die Vorrichtung ferner folgende Merkmale aufweist:

eine Polarisierungseinrichtung (36, 58, 84) in dem optischen Weg zum Polarisieren des optischen Rauschens in eine Komponente mit einer ersten Polarisation und eine Komponente mit einer zweiten Polarisation und zum Durchlassen optischer Rauschkomponenten mit der

ersten Polarisation zu einem Ausgang (40, 62, 102); und

einen Faraday-Rotator (30, 54, 96) in dem optischen Weg zum Drehen der Polarisation der optischen Rauschkomponenten mit der zweiten Polarisation in eine dritte Polarisation und danach zum Drehen optischer Rauschkomponenten mit der dritten Polarisation zurück in die erste Polarisation,

wodurch optische Rauschkomponenten außerhalb der vorbestimmten Bandbreite bei aufeinanderfolgenden Durchläufen gedämpft werden, und optische Rauschkomponenten innerhalb der vorbestimmten Bandbreite bei aufeinanderfolgenden Durchläufen verstärkt und auf die Drehung in die erste Polarisation hin zu dem Ausgang durchgelassen werden.

2. Die Vorrichtung gemäß Anspruch 1, bei der die Filtereinrichtung (80) ein Transmissionsfilter aufweist.

3. Die Vorrichtung gemäß Anspruch 1, bei der die Reflexionseinrichtung (32) und die Filtereinrichtung (32) in einem Reflexionsfilter enthalten sind.

4. Die Vorrichtung gemäß einem beliebigen vorhergehenden Anspruch, bei der die Polarisationseinrichtung (36, 58, 84) einen Polarisationsstrahlteiler aufweist.

5. Die Vorrichtung gemäß einem beliebigen vorhergehenden Anspruch, bei der die Verstärkungseinrichtung (20, 50, 93) einen Pumplaser (25, 94), einen Wellenlängenteilungs-Multiplexer (24, 92) und eine dotierte Verstärkungsfaser (22, 90) aufweist.

6. Die Vorrichtung gemäß einem beliebigen vorhergehenden Anspruch, die ferner eine Verzögerungsleitung (42) in dem optischen Weg aufweist.

7. Ein Verfahren zum Erzeugen eines optischen Rauschens einer vorbestimmten Bandbreite mit folgenden Schritten:

(a) Erzeugen eines optischen Rauschens durch Spontanemission;

(b) Leiten des optischen Rauschens entlang eines optischen Wegs, der mehrmals durch einen Verstärker (20, 50, 93) läuft;

(c) Filtern (32, 34; 56; 80) des optischen Rauschens, während dasselbe entlang des optischen Wegs läuft, um optische Komponenten außerhalb der vorbestimmten Bandbreite zu dämpfen; dadurch gekennzeichnet, daß das Verfahren ferner folgende Schritte aufweist:

(d) Polarisieren (36, 58, 84) des optischen Rauschens, während dasselbe entlang des optischen Wegs läuft, in eine Komponente mit einer ersten Polarisation und eine Komponente mit einer zweiten Polarisation;

(e) Drehen (30, 54, 96) der Polarisation des optischen Rauschens bei aufeinanderfolgenden Durchläufen durch den Verstärker, derart, daß nach einer Mehrzahl von Durchläufen durch den Verstärker die Polarisation jeder Komponente, die nicht die erste Polarisation aufweist, in die erste Polarisation gedreht wurde; und

(f) Leiten jeder optischen Rauschkomponente, die die erste Polarisation aufweist, zu einem Ausgang (40, 62, 102).

8. Das Verfahren gemäß Anspruch 7, bei dem sich der optische Weg von einem ersten Tor des Verstärkers (20) durch einen Faraday-Rotator (30) zu einem Reflexionsfilter (32) und dann zurück durch den Faraday-Rotator zu dem Verstärker, und von einem zweiten Tor des Verstärkers (20) durch eine Polarisationsvorrichtung (36) zu einem weiteren Reflexionsfilter (34) und dann zurück zu dem Verstärker erstreckt.

9. Das Verfahren gemäß Anspruch 7, bei dem sich der optische Weg von einem ersten Tor des Verstärkers (93) durch einen Faraday-Rotator (96) zu einem Reflektor (98) und daraufhin zurück durch den Faraday-Rotator zu dem Verstärker, und von einem zweiten Tor des Verstärkers (93) durch eine Polarisationsvorrichtung (84) zu einem weiteren Reflektor (100) und daraufhin zurück zu dem Verstärker und durch ein Filter (80) erstreckt.

10. Das Verfahren gemäß Anspruch 7, bei dem sich der optische Weg von einem ersten Tor des Verstärkers (50) zu einem Reflektor (52) und daraufhin zurück zu dem Verstärker, und von einem zweiten Tor des Verstärkers (50) durch einen Faraday-Rotator (54) und eine Polarisationsvorrichtung (58) zu einem weiteren Reflektor (60) und daraufhin zurück zu dem Verstärker und durch ein Filter (56) erstreckt.

Revendications

1. Un appareil de création d'un bruit optique d'une largeur de bande optique prédéterminée, comprenant:

- un moyen amplificateur (20, 50, 93) disposé

dans un trajet optique de manièr à amplifier des composantes de bruit optique, le moyen d'amplification (20, 50, 93) incluant un moyen de production d'un bruit optique non polarisé par émission spontanée;

- des moyens réfléchissants (32, 34; 52, 60; 98, 100) disposés dans le trajet optique sur les deux côtés dudit moyen amplificateur pour refléter le bruit optique produit par le moyen amplificateur (20, 50, 93) en retour vers le moyen amplificateur (20, 50, 93) pour amplification additionnelle ;

- des moyens de filtre (32, 34; 56; 80) disposés dans le trajet optique pour atténuer des composants de bruit optique situés à l'extérieur de la largeur de bande optique prédéterminée; caractérisé en ce que l'appareil comprend en outre:

- un moyen de polarisation (36, 58, 84) disposé dans le trajet optique de manière à polariser le bruit optique en une composante d'une première polarisation et une composante d'une deuxième polarisation et à transmettre à une sortie (40, 62, 102) des composants de bruit optique de la première polarisation; et

- un rotateur de Faraday (30, 54, 96) disposé dans le trajet optique de manière à faire tourner vers une troisième polarisation la polarisation de composants de bruit optique de la deuxième polarisation et à faire tourner ensuite les composantes de bruit optique de la troisième polarisation en retour vers la première polarisation,

- grâce à quoi des composantes de bruit optique situés à l'extérieur de la largeur de bande prédéterminée sont atténués lors de passages successifs et des composantes de bruit optique situés à l'intérieur de la largeur de bande prédéterminée sont amplifiés lors de passages successifs et sont transmis à la sortie après leur rotation vers la première polarisation.

2. L'appareil selon la revendication 1, dans lequel le moyen de filtre (80) comprend un filtre par transmission.

3. L'appareil selon la revendication 1, dans lequel le moyen de réflection (32) et le moyen de filtre (32) sont compris dans un filtre réfléchissant.

4. L'appareil selon l'une des revendications précédentes quelconque, dans lequel le moyen de polarisation (36, 58, 84) comprend un diviseur de faisceau polarisant.

5. L'appareil selon une revendication précédente quelconque dans lequel le moyen amplificateur (20, 50, 93) comprend un laser de pompage (25, 94), un multiplexeur (24, 92) en longueurs d'ondes et une fibre amplificatrice dopée (22, 90).

6. L'appareil selon l'une des revendications précédentes quelconque comprenant en outre une ligne à retard (42) disposée dans le trajet optique.

7. Un procédé de création d'un bruit optique d'une largeur de bande prédéterminée, le procédé comprenant les étapes consistant à:

(a) engendrer un bruit optique par émission spontanée;

(b) diriger le bruit optique le long d'un trajet optique qui traverse plusieurs fois un amplificateur (20, 50, 93);

(c) filtrer (32, 34; 56; 80) le bruit optique au fur et à mesure qu'il se propage le long du trajet optique de manière à atténuer les composants optiques situés à l'extérieur de la largeur de bande prédéterminée; caractérisé en ce que le procédé comprend en outre les étapes consistant à:

(d) polariser (36, 58, 84) le bruit optique au fur et à mesure qu'il se propage le long du trajet optique en un composant d'une première polarisation et un composant d'une deuxième polarisation;

(e) faire tourner (30, 54, 96) la polarisation du bruit optique lors de traversées successives de l'amplificateur d'une manière telle que la polarisation d'une composante quelconque qui n'est pas de la première polarisation a été tourné après plusieurs traversées de l'amplificateur vers la première polarisation; et

(f) transmettre à une sortie (40, 62, 102) toute composante de bruit optique de la première polarisation.

8. Le procédé selon la revendication 7, dans lequel le trajet optique s'étend à partir d'un premier orifice de l'amplificateur (20) à travers un rotateur de Faraday (30) vers un filtre réfléchissant (32) et en revient à travers le rotateur de Faraday vers l'amplificateur, et s'étend à partir d'un deuxième orifice de l'amplificateur (20) à travers un polariseur (36) vers un autre filtre réfléchissant (34) et en revient dans l'amplificateur.

9. Le procédé selon la revendication 7, dans lequel le

trajet optique s'étend à partir d'un premier orifice de l'amplificateur (93) à travers un rotateur de Faraday (96) vers un réflecteur (98) et en revient à travers le rotateur de Faraday vers l'amplificateur, et s'étend à partir d'un deuxième orifice de l'amplificateur (93) à travers un polariseur (84) vers un autre réflecteur (100) et en revient vers l'amplificateur, et à travers un filtre (80).

10. Le procédé selon la revendication 7, dans lequel le trajet optique s'étend à partir d'un premier orifice de l'amplificateur (50) vers un réflecteur (52) et en revient vers l'amplificateur, et à partir d'un deuxième orifice de l'amplificateur (50) à travers un rotateur de Faraday (54) et un polariseur (58) vers un autre réflecteur (60) et en revient vers l'amplificateur, et traverse un filtre (56).

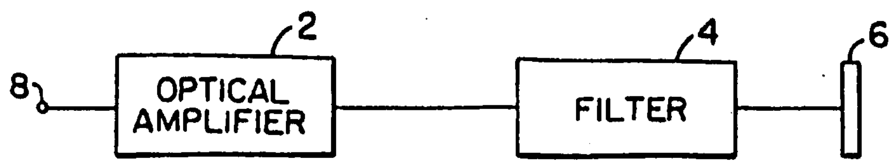


FIG. 1.

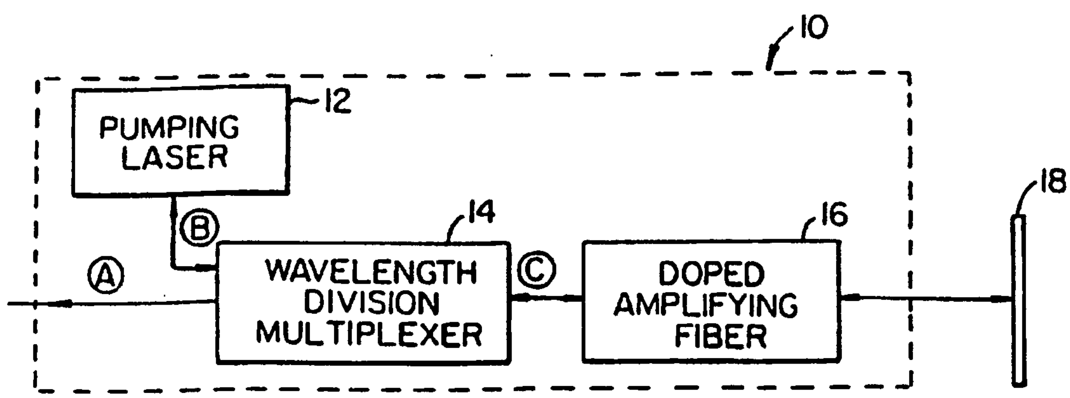


FIG. 2. PRIOR ART

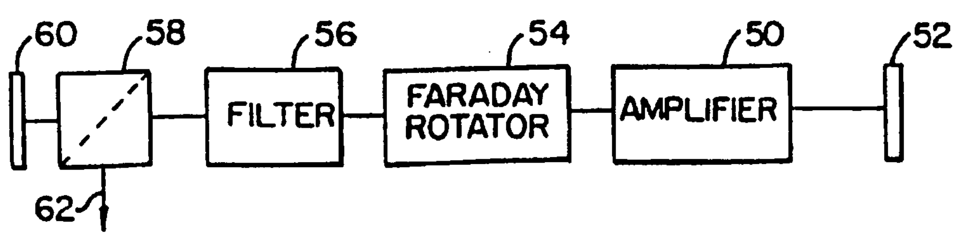
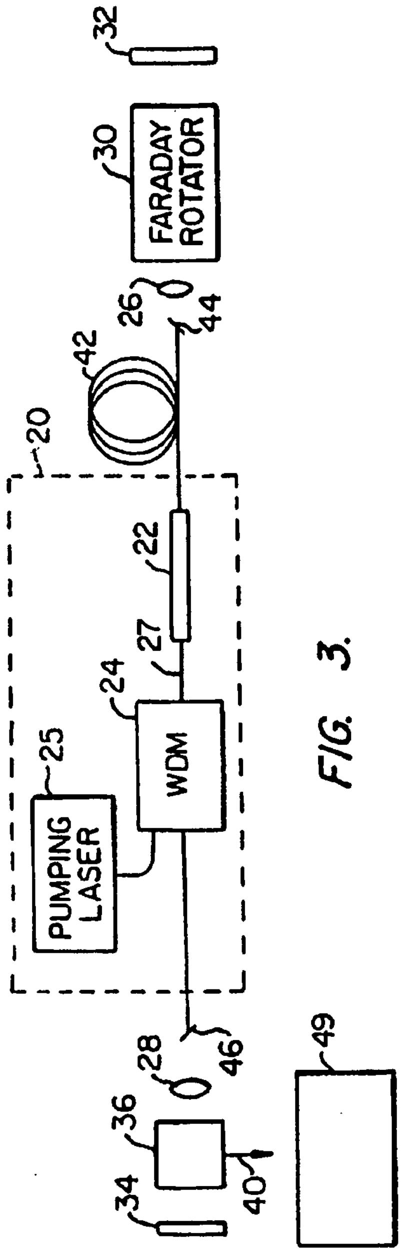
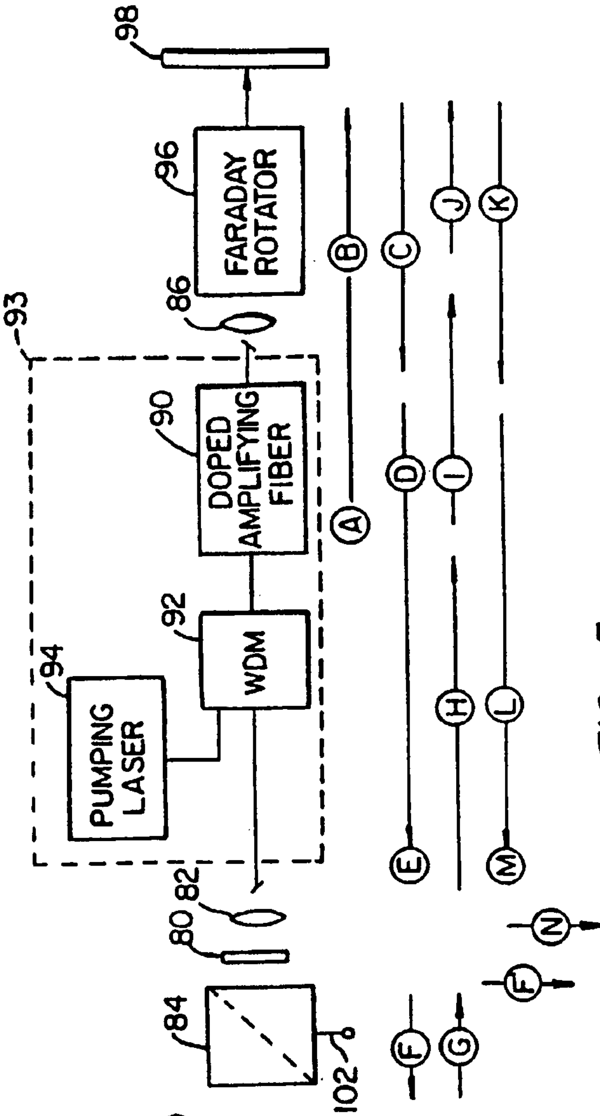


FIG. 4.



20
PUMPING LASER
25
WDM
24
27
22
42
26
44
FARADAY ROTATOR
30
32
28
46
36
34
40
49

FIG. 3.



93
PUMPING LASER
94
WDM
92
DOPED AMPLIFYING FIBER
90
86
FARADAY ROTATOR
96
98
82
80
84
102
100
A
B
C
D
E
F
G
H
I
J
K
L
M
N

FIG. 5.